D-meson production in jets in pp and PbPb collisions with the CMS detector

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Why study D meson production in jets?

Enhancement of low $p_T$ light hadrons at large angles about jets

- Light hadron jet shape analysis


CMS PbPb, $\sqrt{s_{NN}} = 2.76$ TeV
L $dt = 150 \mu$b$^{-1}$
anti-$k_T$ jets: $R = 0.3$

$\rho(r)_{\text{PbPb}} / \rho(r)_{pp}$ vs. $r$

- $p_T^{\text{jet}} > 100$ GeV/c
- $0.3 < |\eta|^{\text{jet}} < 2$
- $p_T^{\text{track}} > 1$ GeV/c

K, $\pi$

arXiv:1803.00042, Accepted by JHEP
Why study D meson production in jets?

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  - Light hadron jet shape analysis

- **How to explain**
  - medium-induced gluon radiation?
  - medium response?
  - multiple scatterings?
  - ……..

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pp 27.4 pb$^{-1}$ (5.02 TeV) PbPb 404 µb$^{-1}$ (5.02 TeV)

anti-$k_T$, $R = 0.4$ jets, $p_T > 120$ GeV, $|\eta| < 1.6$

$0.7 < p_T^{\text{track}} < 300$ GeV

PbPb 0-10%

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Why study D meson production in jets?

Enhancement of low $p_T$ light hadrons at large angles about jets
   Light hadron jet shape analysis

How to explain
   medium-induced gluon radiation?
   medium response?
   multiple scatterings?
   ……

Vary mass of the associated hadrons!
   Heavy flavor
Why study D meson production in jets?

Even more …

Production mechanism of charm

- The role of gluon splitting
- Recombination in the medium

Heavy quark behavior and interactions in the medium

- Energy loss
  - Inclusive measurements:
    - heavy-flavor hadrons spectra, azimuthal anisotropy, heavy flavor tag jets
  - Details on interaction of heavy quarks about jet directions
- Diffusion
Dataset and observables

- **Jet-triggered** events in **pp** (27.4 pb\(^{-1}\)) and **PbPb** (404 μb\(^{-1}\)) collisions at \(\sqrt{s_{\text{NN}}} = 5.02\) TeV collected in 2015 with the CMS detector
- **MinimumBias** events are used for background subtraction
- Cross-checked with D-triggered events
Dataset and observables

- **Jet-triggered** events in **pp** (27.4 pb$^{-1}$) and **PbPb** (404 μb$^{-1}$) collisions at $\sqrt{s_{NN}} = 5.02$ TeV collected in 2015 with the CMS detector.

- Angular distribution of D$^0$ with respective to the jet axis:

\[
\frac{1}{N_{JD}} \frac{dN_{JD}}{dr} = r = \sqrt{\Delta \phi_{JD}^2 + \Delta \eta_{JD}^2}
\]

- The final distribution is normalized to unity in $r < 0.3$
- No $p_T$ weight as light-hadron jet shape analysis
Jet-triggered events in pp (27.4 pb\(^{-1}\)) and PbPb (404 \(\mu\)b\(^{-1}\)) collisions at \(\sqrt{s_{NN}} = 5.02\) TeV collected in 2015 with the CMS detector.

- **D\(^0\) → K\(\pi\)**
- **D\(^0\) vertex reconstruction**
  - pairing two tracks
  - kinematic fitter
- **Topological selections**
  - Pointing angle (\(\alpha\)) < \(\sim 0.04\)
  - 3D decay length (\(d_0\)) normalized by its error > \(\sim 3\)
  - Secondary vertex prob > \(\sim 0.05\)
- **\(|y^{D}| < 2\)**
- **Two \(p_T\) bins**
  - \(4 < p_T^{D} < 20\) GeV
  - \(p_T^{D} > 20\) GeV
D and jets reconstruction and selections

- **Jet-triggered** events in pp (27.4 pb\(^{-1}\)) and PbPb (404 \(\mu\)b\(^{-1}\)) collisions at \(\sqrt{s_{\text{NN}}} = 5.02\) TeV collected in 2015 with the CMS detector

- **Particle flow jets**
- **anti-\(k_T\), R = 0.3**
- \(p_T^{\text{jet}}> 60\) GeV/c
- \(|\eta^{\text{jet}}| < 1.6\)

- \(D^0\rightarrow K\pi\)
- \(D^0\) vertex reconstruction
  - pairing two tracks
  - kinematic fitter
- Topological selections
  - Pointing angle (\(\alpha\)) < \(\sim 0.04\)
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Analysis strategy

- **Reconstruct** jets and D⁰ candidates
- **Jet energy correction**
- **Pair** selected D⁰ candidates with *every* selected jet in the same event
- Extract raw yield via **fitting invariant mass** in bins of r
- Correct **acceptance** and **efficiency** by simulations in bins of r
- **Subtract background** via event mixing technique
- Correct the **resolution effect** by the jet resolution from simulations
Raw $D^0$ yield extraction

Mass distributions fitted by
- Double gaussian (Signal)
- 3rd order polynomial (Combinatorial)
- Single gaussian ($K$-$\pi$ swapped)
  - Candidates with wrong mass assignment
Event mixing technique

- **Signal**: jets and $D^0$ mesons from the same hard scattering
- **Background**: fake jets, jets and $D^0$ mesons in underlying events, …
Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

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<table>
<thead>
<tr>
<th>Raw D</th>
<th>MB D</th>
<th>Raw jets</th>
<th>MB jets</th>
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Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

Raw D  MB D

- Raw jets

MB jets
Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

**Raw D**

**MB D**

**Raw jets**

**MB jets**
Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

Raw $D$

MB $D$

 Raw jets

 MB jets

- $D^0$ mesons
- Jets

$\text{raw } D$

$\text{signal jet}$

$\text{bkg } D$

$\text{signal jet}$

$\text{signal } D$

$\text{signal jet}$
Background subtraction

- **Signal** = Raw - Background
- Background contributions are much smaller than signal
Results

Low $D p_T$: $4 < p_T^D < 20$ GeV/c

- Low $D p_T$: reach maximum at $0.05 < r < 0.1$
- High $D p_T$: fall rapidly as a function of $r$

High $D p_T$: $p_T^D > 20$ GeV/c
Results

Low $D_{p_T}$: $4 < p_T^D < 20$ GeV/c

- Predictions from PYTHIA 8
  - Low $D_{p_T}$: produce a wider radial profile than measurements
  - High $D_{p_T}$: agree with measurements

CMS-PAS-HIN-18-007
Results

**Low \( D_pT: \) \( 4 < p_{T\,D} < 20 \) GeV/c**

- The ratio of PbPb over pp:
- Low \( D_pT: \) increases as a function of \( r \)
  - Hint that \( D^0 \) are further from jet axis in PbPb than pp
- High \( D_pT: \) consistent with unity

**High \( D_pT: \) \( p_{T\,D} > 20 \) GeV/c**
Summary

- First measurement of the radial profile of $D^0$ mesons in jets in PbPb and pp
  - Hint of wider $D^0$ radial profile in PbPb collisions at $4 < p_T^{D} < 20$ GeV/c
  - Ratio of PbPb/pp is consistent with unity at $p_T^{D} > 20$ GeV/c
- Provides new experimental constraints on
  - heavy-flavor production
  - heavy quark energy loss and diffusion

The MIT group's work was supported by US DOE-NP
Back up

Thanks for your attention!
Raw $D^0$ yield extraction

**CMS Preliminary**

*Data*
- $p_T^D > 20$ GeV/c
- $|y^D| < 2$
- $p_{T}\text{jet} > 60$ GeV/c
- $|\eta_{\text{jet}}| < 1.6$

*Fit*
- $0.05 < r < 0.1$

**Signal**
- Combinatorial
- K-π swapped

*CMS Preliminary*

*Data*
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**Signal**
- Combinatorial
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**CMS-PAS-HIN-18-007**
Background subtraction

- Raw = signal + background
- Four correlations
  - Raw jet + Raw D
  - MB jet + Raw D
  - Raw jet + MB D
  - MB jet + MB D

CMS
Preliminary

- 404 μb⁻¹ (5.02 TeV PbPb)
- 4 < p_T^D < 20 GeV/c
- |y^D| < 2
- |y^{jet}| < 1.6
- p_T^{jet} > 60 GeV/c
- |y^{jet}| > 2

CMS-PAS-HIN-18-007

Jing Wang (MIT), D meson production in jets, QM2018 (Venice)
Analysis strategy

- raw reco D
- raw reco jet

- raw reco D
- raw reco jet

- raw reco D
- reco jet

- gen D
- reco jet

- signal gen D
- signal reco jet

- signal gen D
- signal sgen jet

- signal gen D
- signal gen jet

- Residual JEC
- Invariant mass fit + Acc x Eff correction
- Background subtraction event-mixing method
- Residual correction for non-closure
- Resolution correction
D⁰ meson production

- $c \rightarrow D^0$: $O(50\%)$ of $c$ cross-section
- $D^0 \rightarrow K\pi$: $3.93 \pm 0.04\%$
- $D^0 c\tau = 122.9 \, \mu m$
Outlook

- Higher statistics with 2018 PbPb data
- Centrality dependence of the radial profile of $D^0$ mesons
- Fragmentation function of $D^0$ mesons in jets